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Book of Abstracts
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Kellie Ann Beall, Editor

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Gaithersburg, Maryland 20899

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Smoke Detection by Ultrasound

[Two-Page Abstract]

By David K. Churches, Dr. Ed da-Silva (Open University - UK), David Holifield (UWIC - UK)

The paper discusses a smoke detection device that uses Ultrasound as a detection principle. The heart of the device is a double layer perforated matrix board which facilitates a unique perturbated flow pattern in a smoke plume at laminar velocities, that enables the Ultrasound medium to readily detect the presence of smoke particulates.

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1. Introduction

Ultrasound has long been used as a detection medium in industrial and medical applications, but has not proved to be practical in the detection of post combustion particulates such as smoke for every day use. Although laboratory experimentation for many years has used Ultrasound as smoke detection medium, its adaptation into practical device for post combustion detection at a range of ambient conditions has proved to be problematic.

This research work has attempted to overcome many of the difficulties and demonstrates a method that may be further developed into a practical Ultrasound smoke detector device for every day use.

In order to more fully understand the difficulties of smoke detection by Ultrasound its worthwhile generalising on ambient conditions in the post combustion zone.

At a short distance from the combustion zone, the airflow in flaming fires is usually observed to be turbulent in nature, while in smouldering fires the airflow is usually seen to be laminar.

At a larger distance from the combustion zone smoke plumes from many fire types may develop an isotropic laminar pattern where the fluid flow may be described as semi-viscous. Here the friction forces seem to predominate, and the plume adopts the typical homogeneous structure of a typical fully developed smoke plume.

At an even greater distance from the combustion zone the plume may adopt a semi-inviscid flow pattern where the inertial forces are predominant. Here the flow of the homogeneous plume usually becomes polytropic and appears to break up as the smoke particulates are dispersed in the ambient air mass.

Analysis of smoke plume fluid flow dynamics over the last few years has shown that the plume travel appears initially to be dependent on the thermal entropy of the combustion processes. While later in the plume travel the fluid flow dynamics are more dependant ambient effects such as temperature, local air velocity, relative humidity, and the ergonomic flow of the combustion products.

In conclusion, it may be correct to say that there is no typical position for a practical smoke detection device. Therefore, a practical smoke detection device should detect the presence of smoke particulates under a variety of conditions. This may be when the plume fluid flow is turbulent or laminar, and when the flow pattern is isotropic and semi-viscous, or when it is semi-inviscid and polytropic.

The myriad of fire types, fluid flow patterns, and ambient conditions, has made practical smoke detection by Ultrasound very difficult. This is especially true at low smoke densities and when the flow is laminar at low relative air velocities. This research work developed a method that demonstrates that smoke particulates can be detected in this flow region.

2. Double Layer Matrix Board

The Double Matrix Board is heart of the smoke particulate detection method used in this research work. In many ways it is a unique and original approach to detecting the presence of fine particulates in air suspension at low plume velocities (typically 0.05 m/sec).

The Double layer Matrix as its name implies, is two separate layers of compressed fibreboard perforated with a regular array of apertures of capillary diameter (1 mm ϕ). The double layer board is mounted directly in a moving smoke plume perpendicular to the direction of the flow.

The conventional method of detecting the difference between two dissimilar media sequentially passing through an Ultrasound wave is to measure the Doppler shift frequency. However, the sensitivity of the detector system relies heavily on a rapid frequency shift to be effective. When the Doppler shift is lowered it becomes increasingly more difficult to differentiate between a genuine media density change and that created by ambient noise and atmospheric effects.

This is the case when smoke particulates are introduced into an air volume at a slow rate (such as the inchoate fire stage) when the relative air velocity is low. The problem is further compounded when the density change with time continues at a slow rate, when very high densities may eventually be present with only a small or insignificant change in the Doppler shift frequency.

The Double Matrix Board System has two main properties that enable the detection apparatus to be sensitive to smoke plumes at low relative air velocities. And when the two properties combine in tandem, their synergy increases the sensitivity of the detection system by several factors when compared to either property operating alone. Broadly two particular properties are as follows:

- Induces a disassociated flow pattern (pseudo-turbulence) in the smoke plume as it enters the double matrix layer (strainer effect) at laminar velocities when the detector system has a low Reynolds Number. And when the smoke plume exits the double matrix layer, a rapid reassociation is induced within the plume and a cohesive and structured laminar flow pattern is reformed.

- A spatial resonance is formed when the combination of the critical dimensions of the double layer matrix array are similar to a function of the half-wave (½ λ) of a time varying Ultrasonic wave emanating through the detector equipment.

During this research work, the smoke from several differing fire types at varying optical densities was passed through the detector equipment. It was noted that the rate of the onset of pseudo-turbulence (disassociated flow pattern) and the speed of the subsequent reassociation of the cohesive laminar flow, differed for dissimilar smoke types and varying optical smoke densities.

It was also observed that the differing perturbated flow patterns of a variety of dissimilar smoke types had another affect within the Double Layer Matrix Board. The frequency of the incident Ultrasound wave within the apparatus was tuned to the spatial and cavitational resonant frequency of the Double Layer Matrix Board. This meant that the system was particularly sensitive to a media density change within the Double Matrix interstitial cavity, such as the introduction of smoke particulates into the slow moving air column passing through the apparatus.

Since the apparatus uses a single point piezo detector mounted just after the Double Layer Matrix Board, it receives the Ultrasound signal from each aperture across the whole area of the matrix board at different time intervals. Therefore, the composite signal received at the single point piezo detector is the algebraic sum of all the Ultrasound signals from each aperture. When a density change occurs in the media within the apparatus such as the introduction of smoke particulates, it was observed that the frequency bandwidth (phase delay) and the amplitude (group delay) correspondingly changed in the composite signal.

3. Discussion

It was observed during the research work, that the Double Layer Matrix Board System could adequately detect a density change in a Two-Phase Fluid Flow such as smoke particulates in air suspension. The observations also demonstrated that the Double Layer Matrix Board System could form the basis of a practical smoke detector with further development work. The Author(s) also speculate that other research into the measurement of slow moving Two-Phase fluids might also find the method useful.